



MARKSCHEME

SPECIMEN PAPER

PHYSICS

Higher Level

Paper 3

General Marking Instructions

Subject Details: Physics HL Paper 3 Markscheme

Mark Allocation

Candidates are required to answer **ALL** questions in Section A [**15 marks**] and all questions from **ONE** option in Section B [**30 marks**].
Maximum total = [**45 marks**].

Markscheme format example:

Question		Answers	Notes	Total
4.	b ii	the displacement and acceleration ✓ are in opposite directions ✓	<i>Accept force for acceleration.</i>	2

- Each row in the “Question” column relates to the smallest subpart of the question.
- The maximum mark for each question subpart is indicated in the “Total” column.
- Each marking point in the “Answers” column is shown by means of a tick (✓) at the end of the marking point.
- A question subpart may have more marking points than the total allows. This will be indicated by “**max**” written after the mark in the “Total” column. The related rubric, if necessary, will be outlined in the “Notes” column.
- An alternative wording is indicated in the “Answers” column by a slash (/). Either wording can be accepted.
- An alternative answer is indicated in the “Answers” column by “**OR**” on the line between the alternatives. Either answer can be accepted.
- Words in angled brackets < > in the “Answers” column are not necessary to gain the mark.
- Words that are underlined are essential for the mark.
- The order of marking points does not have to be as in the “Answers” column, unless stated otherwise in the “Notes” column.
- If the candidate’s answer has the same “meaning” or can be clearly interpreted as being of equivalent significance, detail and validity as that in the “Answers” column then award the mark. Where this point is considered to be particularly relevant in a question it is emphasized by ***OWTTE*** (or words to that effect) in the “Notes” column.
- Remember that many candidates are writing in a second language. Effective communication is more important than grammatical accuracy.

12. Occasionally, a part of a question may require an answer that is required for subsequent marking points. If an error is made in the first marking point then it should be penalized. However, if the incorrect answer is used correctly in subsequent marking points then **follow through** marks should be awarded. When marking, indicate this by adding **ECF** (error carried forward) on the script. “ECF acceptable” will be displayed in the “Notes” column.
13. Do **not** penalize candidates for errors in units or significant figures, **unless** it is specifically referred to in the “Notes” column.

SECTION A

Question		Answers	Notes	Total
1.	a	$a = 330 \text{ } \langle \text{m s}^{-1} \rangle \checkmark$		1
	a	$b_{\text{max}} = \left\langle \frac{344 - 316}{40} \right\rangle = 0.70 \text{ } \langle \text{m s}^{-1} \text{ } ^\circ\text{C}^{-1} \rangle \checkmark$ $b_{\text{min}} = \left\langle \frac{340 - 318}{40} \right\rangle = 0.55 \text{ } \langle \text{m s}^{-1} \text{ } ^\circ\text{C}^{-1} \rangle \checkmark$ $\Delta b = \left\langle \frac{0.70 - 0.55}{2} \right\rangle = 0.075 \approx 0.08 \text{ } \langle \text{m s}^{-1} \text{ } ^\circ\text{C}^{-1} \rangle \checkmark$		3
	a	$b = 0.59 (\pm 0.08) \text{ } \langle \text{m s}^{-1} \text{ } ^\circ\text{C}^{-1} \rangle \checkmark$	<i>Allow 0.593 (± 0.075).</i>	1
	b	$\theta = \left\langle \frac{-330}{0.6} \right\rangle = -550 \text{ } \langle ^\circ\text{C} \rangle \checkmark$		1
	b	temperature is unphysical OR there is no temperature below -273°C OR this temperature cannot be right \checkmark it appears that the linear fit model cannot be extrapolated far from 0°C \checkmark		2

Question		Answers	Notes	Total
2.	a	the estimated percentage uncertainty in g \langle is $2 \times 0.3 + 0.6 \rangle = 1\%$ ✓	Accept 1.2 %.	1
	b	<p>use more than one height ✓</p> <p>obtain g from a suitable graph \langle of height h versus $t^2 \rangle$ ✓</p> <p>g is twice the gradient ✓</p> <p>OR</p> <p>use a smaller ball \langle to reduce air resistance \rangle ✓</p> <p>use a \langle much \rangle larger height ✓</p> <p>repeat many times \langle to get an average of time \rangle ✓</p>	<p>Allow h versus t^2 or \sqrt{h} versus t or $\log h$ log t.</p> <p>Analysis of g must fit quoted graph.</p>	3

3.	a	the actual specific heat capacity will be less than calculated value ✓	Do not allow a bald answer.	2
	b	<p>more thermal energy is transferred to the calorimeter and contents than accounted for ✓</p> <p>metal may not have been heated uniformly</p> <p>OR</p> <p>metal may not all be at 100°C ✓</p> <p>energy was lost to air during the transfer ✓</p> <p>energy may have been lost to the air through the calorimeter ✓</p> <p>water may not be at uniform temperature ✓</p>		1 max

SECTION B

Option A — Relativity

Question	Answers	Notes	Total
4. a	Maxwell's equations implied a speed of light independent of its source OR in Newtonian mechanics, speed of light depends on velocity of source ✓ Einstein trusted Maxwell's equations OR Einstein modified Newtonian mechanics ✓		2
b i	magnetic ✓		1
b ii	if a force exists in one ⟨inertial⟩ frame a force must exist in any other ⟨inertial⟩ frame ✓ cannot be magnetic because the proton is at rest in S' ✓	Accept discussion in terms of acceleration as equivalent to force. Accept an answer in terms of electric field.	2

5. a i	$\langle \frac{900}{c} \rangle \Rightarrow 3.0 \times 10^{-6} \langle s \rangle$ ✓		1
a ii	$\gamma = \langle \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} = \frac{1}{\sqrt{1 - 0.64}} \Rightarrow \frac{5}{3} \approx 1.67$ ✓ $\Delta t = \langle \gamma \left[\Delta t' + \frac{v \Delta x'}{c^2} \right] \Rightarrow \frac{5}{3} \left[3.0 \times 10^{-6} + \frac{0.80c \times 900}{c^2} \right]$ ✓ $= 9.0 \times 10^{-6} \langle s \rangle$ ✓		3

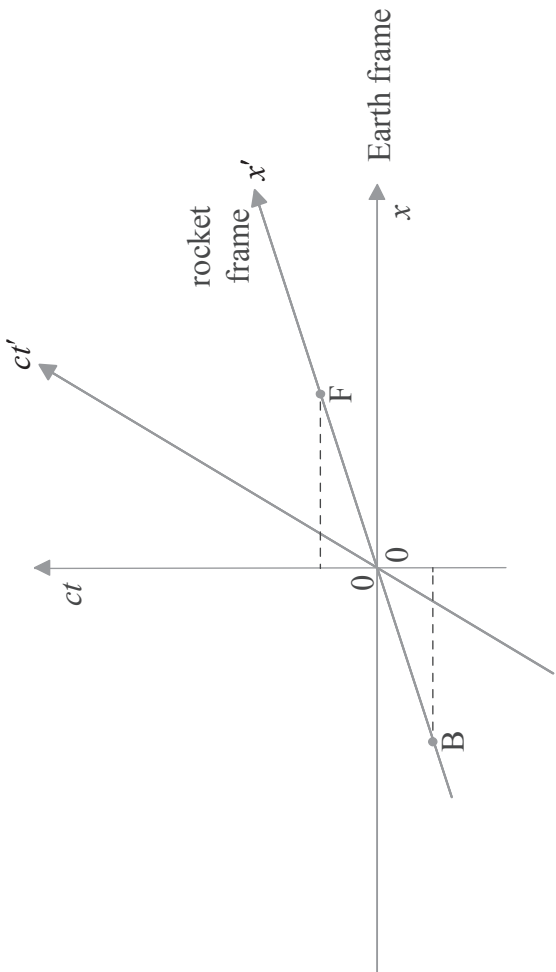
(continued...)

(Question 5 continued)

Question		Answers	Notes	Total
a	iii	$\Delta x = \Delta ct = 3.0 \times 10^8 \times 9.0 \times 10^{-6} \Rightarrow 2700 \text{ m}$ OR $\Delta x = \gamma [\Delta x' + v \Delta t'] = \frac{5}{3} \left[900 + 0.80c \times \frac{900}{c} \right] \Rightarrow 2700 \text{ m} \checkmark$		1
	b	i 	Judge by eye.	3

(continued...)

(Question 5 continued)

Question	Answers	Notes	Total
b ii	 <p>lines through B and F parallel to x-axis ✓ to see that B happened first ✓</p>		2
b iii	$\Delta t = \gamma \left[\Delta t' + \frac{v \Delta x'}{c^2} \right] \Rightarrow \frac{5}{3} \left[0 + \frac{0.80c \times [900]}{c^2} \right] \checkmark$ $\Delta t = 4.0 \times 10^{-6} \text{ s} \checkmark$		2
c	solving for u ✓ correct substitution ✓ correct answer of 0.36c ✓		3

Question		Answers	Notes	Total
6.	a	$pc = \langle \sqrt{E^2 - [mc^2]^2} \rangle = \langle \sqrt{1070^2 - 135^2} \rangle \checkmark$		1
	b	energy: $E_X + E_Y = 1070 \langle \text{MeV} \rangle \checkmark$ momentum: $E_X - E_Y = 1060 \langle \text{MeV} \rangle \checkmark$ solving to get $E_Y = 5 \langle \text{MeV} \rangle \checkmark$		3
7.	a	impossible to distinguish effects of gravity from effects of acceleration OR frame accelerating in outer space with acceleration $\langle a \rangle$ is equivalent to frame at rest in gravitational field $\langle \text{with } g = a \rangle$ OR frame freely falling in gravitational field is equivalent to inertial frame in outer space \checkmark <i>version with accelerating frame:</i> observer is moving relative to source and so light experiences Doppler shift \checkmark motion is away from source and so frequency is reduced \checkmark frame is equivalent to frame at rest in a gravitational field \checkmark OR <i>version with freely falling frame:</i> light received by observer in freely falling frame is blueshifted because of Doppler effect \checkmark but frame is equivalent to inertial frame so frequency cannot change \checkmark so rising light suffers gravitational redshift $\langle \text{to offset the Doppler blueshift} \rangle \checkmark$		1
	a	ii		3

(continued...)

(Question 7 continued)

Question		Answers	Notes	Total
b		$\frac{1}{\sqrt{1 - \frac{1}{1.25}}} \checkmark$		2
		$= 2.24 \text{ (s)} \checkmark$		

Option B — Engineering physics

Question		Answers	Notes	Total
8.	a	$\alpha = \frac{a}{R} \checkmark$ $T \times R = \frac{1}{2}MR^2 \frac{a}{R} \checkmark$ $mg - T = ma \checkmark$ <p>⟨add equations/eliminate tension⟩ to get $mg = ma + \frac{1}{2}Ma \checkmark$</p>		4
	b	$a = \left\langle \frac{24 \times 9.8}{36 + \frac{24}{2}} \right\rangle 5.6 \langle \text{ms}^{-2} \rangle \checkmark$ $v = \left\langle \sqrt{2as} = \sqrt{2 \times 5.6 \times 16} \right\rangle 13.4 \approx 13 \langle \text{ms}^{-1} \rangle \checkmark$ <p>OR</p> $mgh = \frac{1}{2}mv^2 + \frac{1}{2}I^2\omega^2$ <p>OR</p> $mgh = \frac{1}{2}mv^2 + \frac{1}{2}I\frac{v^2}{R^2} \checkmark$ $v = \left\langle \sqrt{\frac{2 \times 24 \times 9.8 \times 16}{24 + 18}} \right\rangle 13.4 \approx 13 \langle \text{ms}^{-1} \rangle \checkmark$	Award [2] for a bald correct answer.	2

(continued...)

(Question 8 continued)

Question	Answers	Notes	Total
b ii	<p>rate of change of L is $I\alpha = I \frac{a}{R}$ ✓</p> $\left\langle \frac{1}{2} MR^2 \frac{a}{R} \right\rangle \Rightarrow \frac{1}{2} \times 36 \times 0.20 \times \frac{24 \times 9.8}{24 + \frac{36}{2}}$ $= 20.2 \approx 20 \langle \text{N m} \rangle$ ✓ <p>OR</p> <p>rate of change of L is Γ (torque on axle) ✓</p> $\Gamma = TR = \frac{1}{2} \times 36 \times \frac{24 \times 9.8}{24 + \frac{36}{2}} \times 0.20$ ✓ $= 20.2 \approx 20 \langle \text{N m} \rangle$ ✓	Award [3] for a bald correct answer.	3
c	$\langle P = 45 \times 9.8 \times 2.0 \rangle \Rightarrow 882 \approx 880 \langle \text{W} \rangle$ ✓		1

Question		Answers	Notes	Total
9.	a	$\langle \text{maximum is at B and so } T_B = 400 \times \frac{8}{2} = \rangle 1600 \langle \text{K} \rangle \checkmark$		1
	b	$W = \langle p\Delta V = \rangle 5.0 \times 10^5 \times [8.0 - 2.0] \times 10^{-3} \checkmark$ $W = 3.0 \times 10^3 \langle \text{J} \rangle \checkmark$	<i>Award [2] for a bald correct answer.</i>	2
	b	$\Delta U = \langle \frac{3}{2} p\Delta V = \frac{3}{2} \times 3.0 \times 10^3 = \rangle 4.5 \times 10^3 \langle \text{J} \rangle \checkmark$	<i>Award [1] for a bald correct answer.</i>	1
	b	$Q = \langle \Delta U + W = 3.0 \times 10^3 + 4.5 \times 10^3 = \rangle 7.5 \times 10^3 \langle \text{J} \rangle \checkmark$	<i>Award [1] for a bald correct answer.</i>	1
	c	$\Delta S = \frac{Q}{T} = -\frac{1390}{400} \checkmark$ $\Delta S = -3.48 \approx -3.5 \langle \text{J K}^{-1} \rangle \checkmark$	<i>Award [1 max] for omitted minus sign.</i> <i>Award [2] for a bald correct answer.</i>	2
	d	$e = \frac{3000 - 1390}{7500} \checkmark$ $e = 0.21 \checkmark$	<i>Award [2] for a bald correct answer.</i>	2
	e	greater \checkmark		1

Question		Answers	Notes	Total
10.	a	smooth flow OR non-turbulent flow OR flow with low Reynolds number ✓ reference to $Av = \text{constant}$ ✓ area of a flowtube decreases above the foil / <i>OWTTE</i> ✓		1
	b	i		2
	b	ii realization that height plays no role ie. $\frac{1}{2} \rho v_1^2 + p_1 = \frac{1}{2} \rho v_2^2 + p_2$ ✓ $p_1 - p_2 = \langle \frac{1}{2} \times 0.95 \times [64^2 - 52^2] \rangle = 661.2 \langle \text{Pa} \rangle$ ✓ $L = \langle [p_1 - p_2] A = 661.2 \times 2.0 \rangle = 1.3 \langle \text{kN} \rangle$ ✓	<i>Award [1 max] for an answer of 137 N. Award [3] for a bald correct answer.</i>	3

Question		Answers	Notes	Total
11.	a	$Q = 2\pi \times \frac{4^2}{4^2 - 3^2}$ ✓ $Q = 14.36 \approx 14$ ✓ the amplitude will increase ✓ the phase will approach $\langle \text{negative} \rangle \frac{\pi}{2}$ relative to the driving force ✓		2
	b	i		1
	b	ii		1

Option C — Imaging

Question		Answers	Notes	Total
12.	a	<p>i</p> <p>the image would be formed at the focal point of the concave mirror OR at a distance of 9.50 m from the centre of the concave mirror <since the object distance is very large> ✓</p> $\langle - \rangle \frac{9.50}{u} = \frac{D_i}{D_o} \checkmark$ $D_i = 9.50 \times \frac{D_o}{u} = 9.50 \times 1.40 \times 10^{-4} \checkmark$ $= 0.00133 \langle \text{m} \rangle$		3
	a	<p>ii</p> <p>the object distance is $-[9.50 - 8.57] = -0.93 \langle \text{m} \rangle \checkmark$</p> <p>so the magnification is $\frac{8.57}{0.93} = 9.215 \checkmark$</p> <p>the diameter of this image is then $9.215 \times 0.00133 = 0.012256 \langle \text{m} \rangle \checkmark$</p>	Ignore incorrect sign.	3
	a	<p>iii</p> <p>angle: $\frac{12.3 \langle \text{mm} \rangle}{98.0 \langle \text{mm} \rangle} = 0.126 \langle \text{rad} \rangle \checkmark$</p> <p>magnification: $\frac{0.126}{1.40 \times 10^{-4}} \checkmark$</p> <p>$= 900 \checkmark$</p>		3

(continued...)

(Question 12 continued)

Question		Answers	Notes	Total
b	i	with parabolic mirrors the problem of spherical aberration is eliminated ✓		1
b	ii	no chromatic aberration ✓ easier/cheaper to make large mirrors than large lenses ✓ easier to support and so can be large ✓ less absorption in glass ✓		1 max
c		a multitude of sources of EM radiation other than visible light have been discovered OR comparison of optical and non-optical images can be made ✓ thus vastly increasing our understanding of what exists in the universe ✓		2

13.	a	i	$\frac{1}{u} = \frac{1}{f} - \frac{1}{v} = \frac{1}{0.40 \times 10^{-2}} - \frac{1}{20 \times 10^{-2}}$ ✓	1
	a	ii	$M = \left\langle -\frac{v}{u} \times \frac{D}{f_e} \right\rangle = \left\langle -\frac{0.20}{4.1 \times 10^{-3}} \times \frac{0.25}{3.2 \times 10^{-2}} \right\rangle$ ✓ $M = 382.8 \approx 380$ ✓	2
	a	iii	$\frac{0.1 \text{ <mm>}}{380} \approx 260 \text{ <nm>}$ ✓	1
	b		attenuation = $\langle 4.6 \times 6.2 \Rightarrow \rangle 28.5 \text{ <dB>}$ ✓ $p = 120 \times 10^{-2.85}$ ✓ power = 0.17 <mW> ✓	3

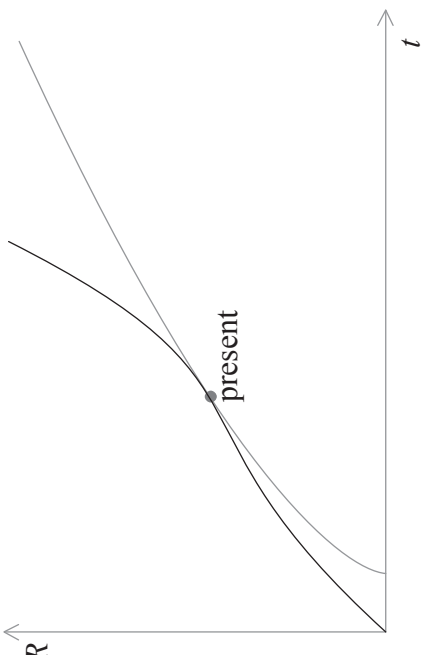
Question		Answers	Notes	Total
14.	a	i	sharpness is a measure of how easy it is to see edges of different organs or different types of tissue in an image ✓	1
	a	ii	use as point-like a source as possible OR reduce backscatter of photons by metal strips <placed along direction of incident X-rays> OR use of computer software to detect and enhance edges ✓	
	b	i	they will be absorbed <doing damage> without contributing to forming the image ✓	1
	b	ii	at 50 keV absorption coefficient is 0.20 cm^{-1} ✓ transmitted intensity fraction is $\langle e^{-0.20 \times 2} = \rangle 67\%$ ✓	2
	c	i	forces protons to make a spin transition ✓	1
	c	ii	allows determination of the point from which the photons are emitted ✓	1
	c	iii	the proton spin relaxation time depends on the type of tissue at the point where the radiation is emitted ✓	1
	d		no harmful ionizing radiation ✓ can better distinguish between different parts of the soft tissue ✓	2

Option D — Astrophysics

Question		Answers	Notes	Total
15.	a	helium ✓		1
	b	$d = \sqrt{\frac{3.8 \times 10^{27}}{4\pi \times 7.6 \times 10^{-14}}} \checkmark$ $d = 6.3 \times 10^{19} \text{ m} \checkmark$ $d = 2000 \text{ pc} \checkmark$	Award [3] for a bald correct answer.	3
	b	no, the distance is too great for the parallax angle to be measured accurately (even from an orbiting telescope) ✓		1
	b	$\left[\frac{M}{M_{\odot}} \right]^{3.5} = 10 \checkmark$ $\frac{M}{M_{\odot}} = \left(10^{\frac{1}{3.5}} \right) = 1.93 \approx 2 \checkmark$	Award [2] for a bald correct answer.	2
	c	estimates of temperatures for star as $7500 (\pm 200) \text{ K}$ and Sun as 6000 K ✓ $10 = \frac{\sigma 4\pi R^2 7500^4}{\sigma 4\pi R_{\odot}^2 6000^4} \checkmark$ $\frac{R}{R_{\odot}} \approx 2 \checkmark$	Accept answers in the range of 1.9 to 2.1.	3
	c	line starting at correct position [$T = 7500 \text{ K}$, $L = 10$] and extending into red giants ✓ ending at white dwarfs ✓		2
	c	equilibrium between gravitational pressure and electron degeneracy pressure ✓ provided final mass is below the Chandrasekhar limit/less than $1.4 M_{\odot}$ ✓		2

Question		Answers	Notes	Total
16.	a	i	the universe is expanding and so wavelengths <like all distances> are being stretched out OR wavelength increasing hence the Doppler redshift is being observed ✓	1
	a	ii	$\langle z = \frac{v}{c} \Rightarrow \rangle v = 0.157 \times 3.0 \times 10^8 = 4.7 \times 10^4 \langle \text{km s}^{-1} \rangle$ ✓ $d = \langle \frac{v}{H} = \frac{4.7 \times 10^4}{71} \Rightarrow \rangle 660 \langle \text{Mpc} \rangle$ ✓	2
	b	i	gravity is pulling back on the galaxies ✓	1
	b	ii	distant supernovae appeared less bright than expected ✓ indicating that they were further away than expected ✓	2

17.	a		the binding energy per nucleon curve peaks at mass number of about 60 ✓ producing heavier elements with fusion is no longer energetically possible ✓	2
	b		absorption of neutrons by nuclei ✓ in a slow process in stars ending at the production of bismuth OR in a fast process in supernovae ending with the very heaviest isotopes <beyond bismuth> ✓	2

Question		Answers	Notes	Total
18.	a	the universe has structure ✓ structures only develop if there are fluctuations/differences in density/differences in temperature <which is what the anisotropies in CMB show> ✓		2
	b	 <p>graph as shown – does not have to start at the origin ✓ the curve becomes flat ✓ the curve can be used to estimate the mass of the galaxy ✓ this mass is greater than the estimate of the mass of the galaxy based on the amount of light radiated ✓</p>		1
	c	i		1
	c	ii		2